Neutrino Factories: History & Organization

1. Pion storage rings with parasitic muon storage
2. Development of intense muon source concepts
3. Interest in Muon Colliders
4. The US Muon Collaboration: Organization
5. Targetry and Cooling R&D Sub-Collaborations
6. Neutrino Factory Ideas
7. Neutrino Factory design studies

Bibliography: Pion Storage Rings with Parasitic Muon Storage

Generating a neutrino beam by storing pions and kaons in rings with long straight sections was first proposed in the 1970's. Some of the secondary muons from the pion decays are also captured within the ring. Downstream of the straight sections there is a pulse of neutrinos from pion decay, followed by a longer pulse of neutrinos from muon decay.

Koshkarev, Preprint ITEP-33, 1974; CERN/ISR-DI/74-62.

Wojcicki (unpublished) 1974

Collins (unpublished) 1974

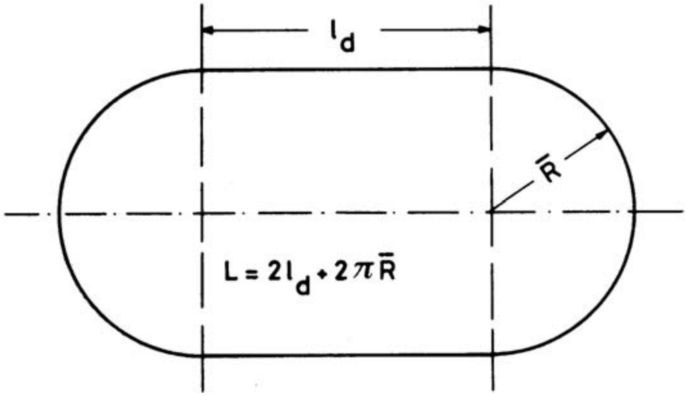
Cline & Neuffer, AIP Conf. Proc. 68, 846 (1980)

A. Bross et al; NIM A 332 (1993) 27

W. Lee et al, FNAL Proposal P860, 1992.

Unfortunately the intensity of the neutrino beams that can be produced in this way are too low (by many orders of magnitude) to produce useful neutrino beams for physics.

Koshkarev, CERN/ISR-DI/74-62 (also Wojcicki & Collins)



Collect high energy secondary particles from proton interactions, and store them in a ring with long straight sections.

The decaying mesons produce a neutrino beam downstream of the straight sections.

Rates from 10^{12} primary protons at 400 GeV

Particle	Momentum GeV/c	Δp GeV/c	Δ Ω ster.	log σ_0	Number of particles accepted
π^+	120 240	12 19	1,5 0,4	+ 1,5 + 0,75	∿ 10^{10} ∿ 7.10^8
π^-	120 240	12 19	1,5 0,4	+ 1,5 + 0,5	∿ 10^{10} ∿ 4.10^8
K^+	120 240	12 19	1,5 0,4	+ 0,75 0	∿ 2.10^9 ∿ 10^8
K^-	120 240	12 19	1,5	0 - 1,75	∿ 3.10^8 ∿ 2.10^6
$\bar{p}$	120 240	12 19	1,5 0,4	- 0,5 - 3	∿ 4.10^7 ∿ 10^5
p	120 240	12 19	1,5 0,4	+ 1 + 1,5	∿ $3\cdot10^9$ ∿ 4.10^9

Fundamental Problem

The production rates for high energy mesons are far too low to be useful.

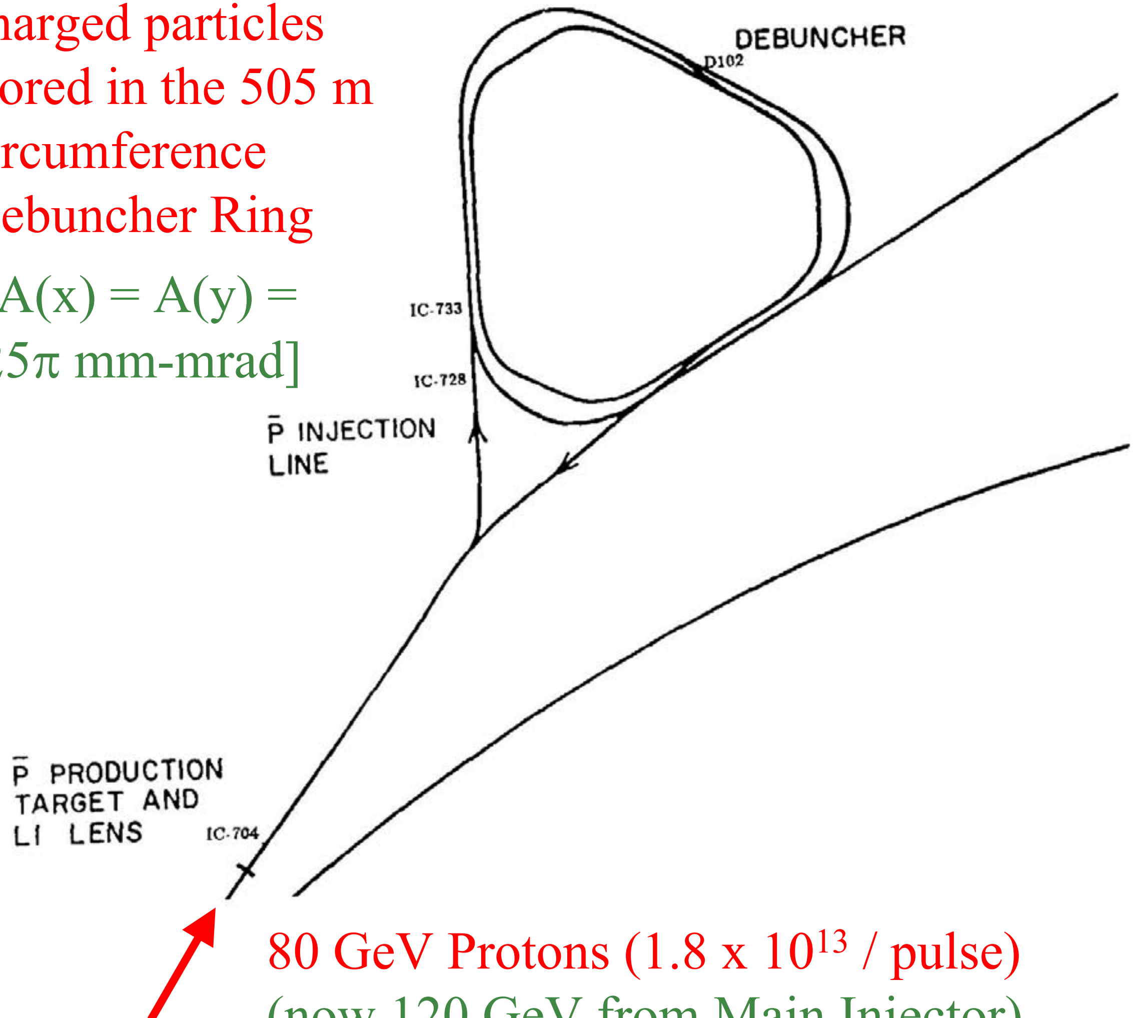
The production rates are higher for lower energy mesons, but the storage ring acceptance is only big enough to capture a tiny fraction of them.

Using The Fermilab Antiproton Debuncher as a Muon Storage Ring

Cline & Neuffer, AIP Conf. Proc. 68, 846 (1980)

8.9 GeV/c (±2%) negatively charged particles stored in the 505 m circumference Debuncher Ring

[A(x) = A(y) = 25π mm-mrad]



80 GeV Protons (1.8 x 10^{13} / pulse)
(now 120 GeV from Main Injector)

Pion lifetime = 1 turn

Estimated 10^{10} muons/pulse from $\pi \rightarrow \mu\nu$ decay) within the ring.

$\rightarrow 8 \times 10^8$ ν per pulse down-stream of one straight section.

One pulse every 10 secs
$\rightarrow 8 \times 10^{14}$ ν per year

We now know that for long baseline neutrino oscillation experiments, this beam intensity is too low by about five orders of magnitude !

Measuring Captured Muons in a Storage Ring

A. Bross et al; NIM A 332 (1993) 27

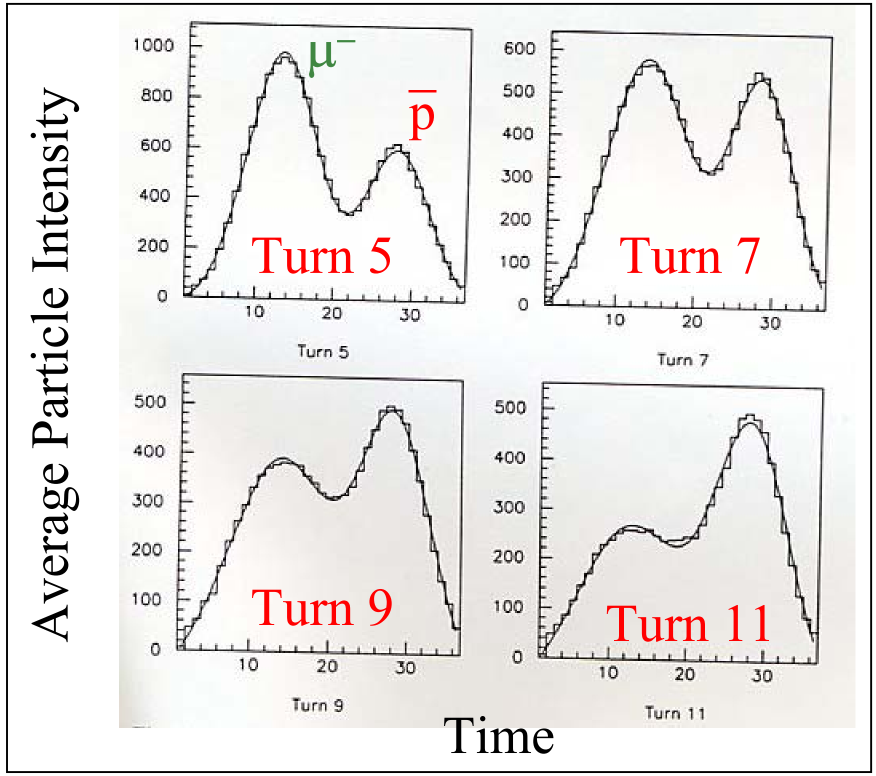
After each turn the antiprotons are delayed (wrt pions, muons …) by about half the bunch spacing … so there is a clear time separation every other turn.

The protons arrive at the target in a train of 84 bunches ($\sigma_t = 1$ ns) with a bunch spacing of 19 ns)

Measured 5×10^8 π captured per 10^{12} protons on target

Calculated 0.018 muons per captured π

After 3 turns measure 0.025 muons per (initially) captured π
$\rightarrow$ $(2.0 \pm 0.4) \times 10^{-5}$ muons / POT



Turn	Flux ($\beta = 1$)	Flux ($\bar{p}$)	$(\beta = 1)/\bar{p}$	$\mu/\bar{p}$
1	33572	–	–	–
3	6251	2126	2.94	0.80
5	2232	1287	1.73	1.12
7	1597	1171	1.36	1.27
9	1306	1132	1.15	1.14
11	934	1122	0.83	0.83

P860: A Search for Neutrino Oscillations using the Fermilab Debuncher

W. Lee et al, FNAL Proposal P860, 1992.

3×10^{12} protons/pulse & one pulse every 2.1 secs $\rightarrow$ $\sim 3 \times 10^4$ useful pulses / day

One muon captured / 3×10^4 protons on target

3×10^{12} captured muons / day

In dedicated running with a modified Debuncher this could be increased to 5.4×10^{13} muons/day

Straight section length = $0.13 \times$ circumference, and first few turns (dominated By pion decay) must be excluded $\rightarrow$ $\sim 5.3 \times 10^{12}$ useful muon decays / day $\rightarrow$ $\sim 10^{15}$ useful muon decays / year

Experiment not approved, the beam intensity was too low to address the physics.

Pion storage rings with parasitic muon storage do not give useful neutrino beams … so what's needed ?

Given our present knowledge of neutrino oscillation parameters, over the last couple of years it has become apparent we need about 10^{20} useful muon decays per year to address the relevant oscillation physics questions.

This intensity requirement could be relaxed by two (three ?) orders of magnitude if neutrino oscillations at the LSND scale are confirmed … but we will still want to aim eventually for a "Neutrino Factory" producing at least 10^{20} useful muon decays per year

Hence, we need to find a way of increasing the number of muons stored in the ring by about FIVE ORDERS OF MAGNITUDE

We need an intense muon source

Intense Muon Source Recipe

1. Make as many charged pions as possible
   → INTENSE PROTON SOURCE
   (In practice this seems to mean one with a beam power of one or a few MW)

2. Capture as many charged pions as possible
   → Low energy pions
   → Good pion capture scheme

3. Capture as many daughter muons as possible within an accelerator
   → Reduce the phase-space occupied by the muons
   → Muon cooling – needs to be fast otherwise the muons decay

Bibliography: Intense Muon Source

A useful neutrino beam facility based on a muon storage ring requires a t least a millimole of muons to be collected per year. The critical concepts for the development of millimole per year muon sources are :

Pion Collection:

Dijikibaev & Lobashev, Sov. J. Nucl. Phys. 49(2), 384 (1989)

Palmer et al., BNL-61581 (1995)

Ionization Cooling:

Kolomensky, Sov. Atomic Energy Vol. 19, 1511 (1965)

Skrinsky & Parkhomchuk, Sov. J. Part. Nucl. 12:223-247 (1981)

Neuffer, Proc. 12th Int. Conf. High Energy Accels (1983) 481; Part. Acc. 14(1983) 75

Skrinsky & Parkhomchuk, Proc. 12th Int. Conf. High Energy Accelerators (1983) 485

Palmer, Neuffer, & Gallardo, AIP Conf. Proc. 335 (1995) 635

By the end of the 1980's all of the basic concepts for millimole muon sources were in place, ready for the serious development of a realistic scheme (requiring lots of invention) .

Beam Cooling

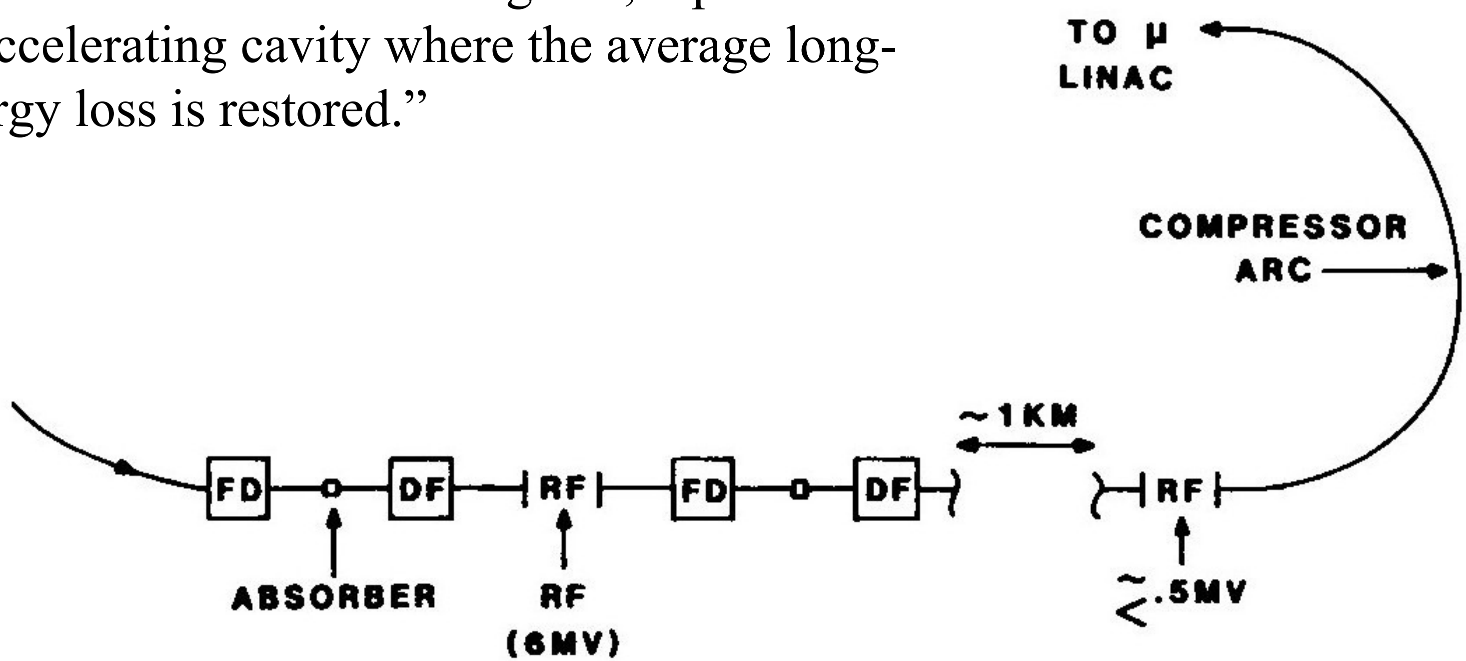
Skrinsky & Parkhomchuk, Sov. J. Part. Nucl. 12:223-247 (1981)

“In elementary-particle and nuclear physics, the basic experimental investigations involve the use of beams. In almost all cases, it is important for these beams to be monochromatic and well collimated. This requires that in the comoving system moving with the mean velocity of the beam particles, the particles must have low velocities, i.e. the beam must have a low temperature. It is therefore important to be able to “cool” beams of charged particles. By this we do not mean adiabatic cooling associated with “spreading of the beam”, i.e., an increase in its size, but a decrease in the six-dimensional phase space occupied by the beam in the space of its generalized coordinates and conjugate momenta; it is necessary to increase the phase density of the beam.”

Ionization Cooling - 1

Neuffer, Proc. 12th Int. Conf. High Energy Accelerators (1983) 481

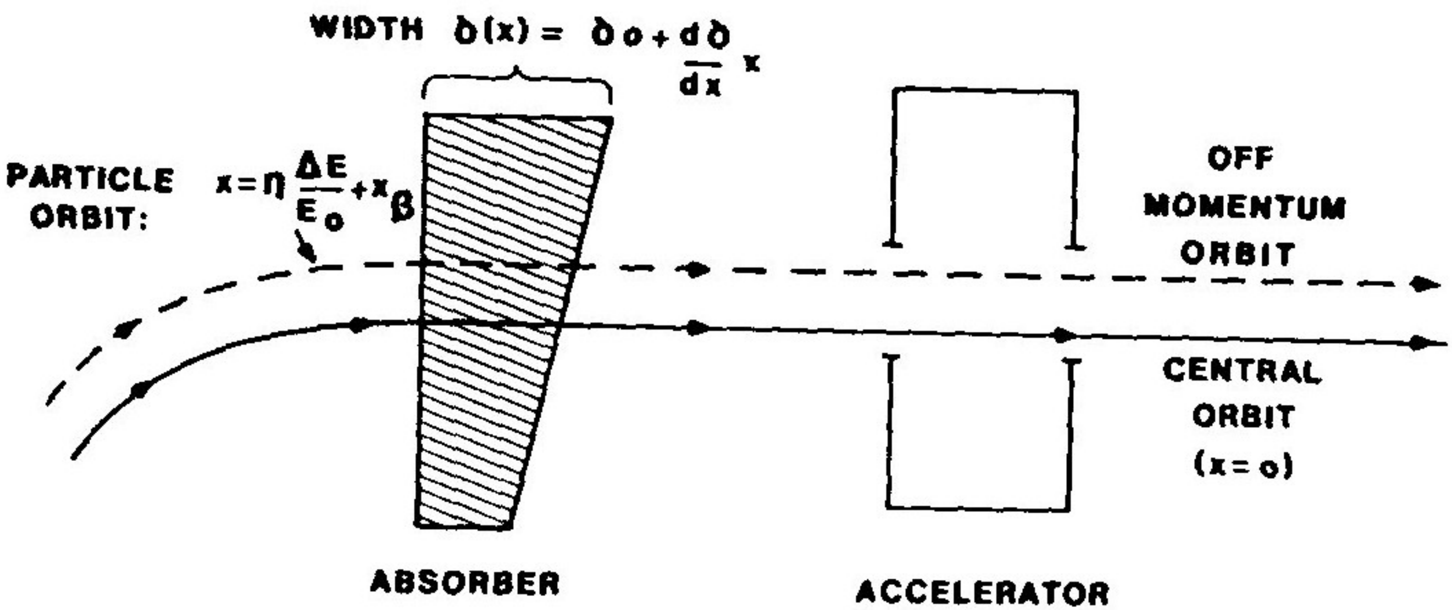
"The muon beam passes through a material medium in which it loses energy, principally through interactions with atomic electrons. Following this, it passes through an accelerating cavity where the average longitudinal energy loss is restored."



Ionization Cooling - 2

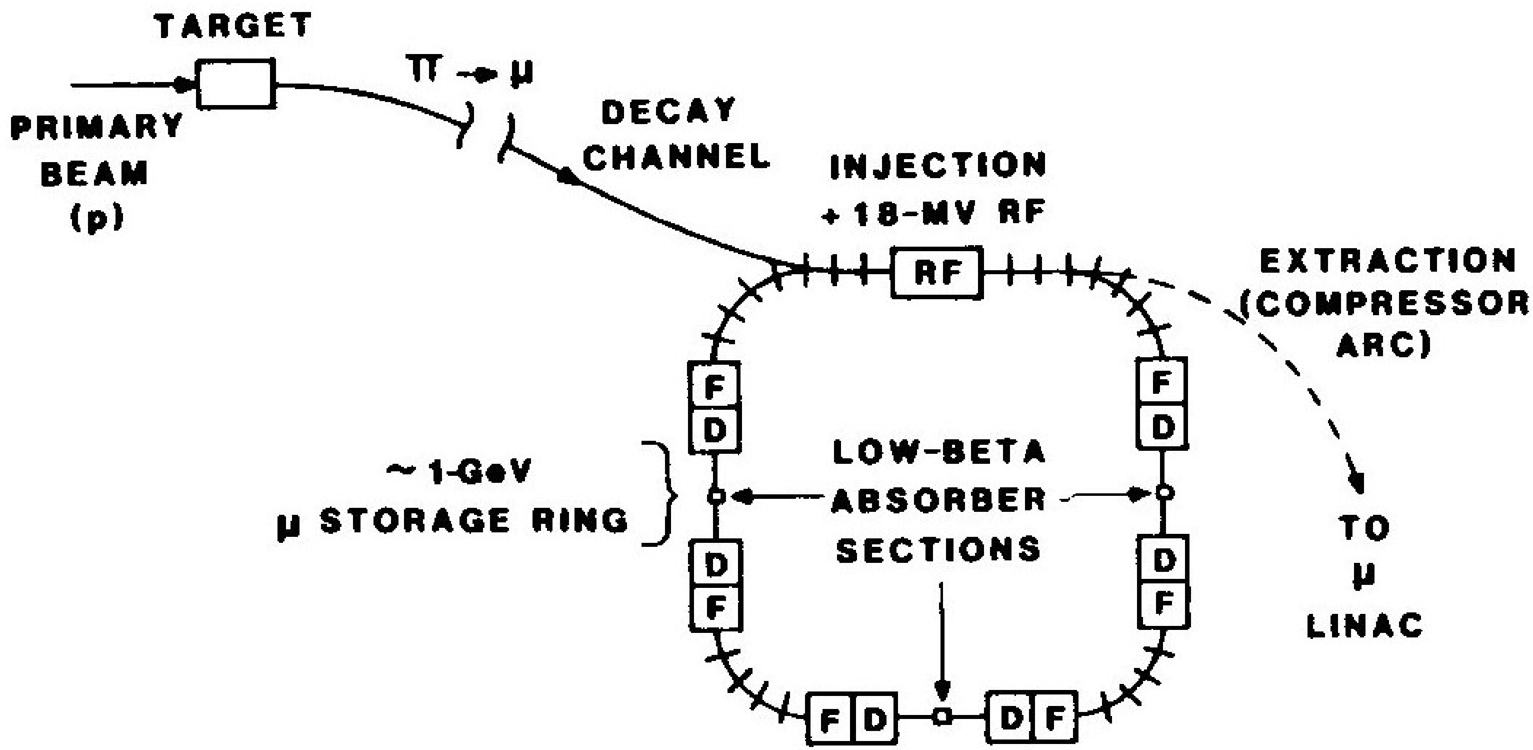
Neuffer, Proc. 12th Int. Conf. High Energy Accelerators (1983) 481

"An exchange in cooling rate between the longitudinal and a transverse dimension can be obtained if a *wedge* absorber in a non-zero dispersion region is used."



Ionization Cooling - 3

Neuffer, Proc. 12th Int. Conf. High Energy Accelerators (1983) 481



The most recent work on cooling channel design is focused on the design of a ring cooler. This was also anticipated in the 1980's, although the present motivation (cooling longitudinally and transversely in a cost-effective system) was not.

Bibliography - Muon Colliders

Taking the initial concepts and developing a realistic millimole muon source required a large effort, and therefore needed a strong motivation. The initial motivation came from the exciting possibility of building a Muon Collider:

Budker, Proc. 7th Int. Conf. High Energy Accel., Yerevan, 1969, p.33

Neuffer, Fermilab Physics Note FN-319 (1979); Particle Accelerators 14 (1983) 75.

Skrinsky & Parkhomchuk, Sov. J. of Nucl. Physics 12 (1981) 3

Muon Collider: A Feasibility Study (Snowmass 1996),
BNL-52503, FNAL-Conf-96/092, LBNL-38946

Higgs Factory Design Study, physics/9901022,
Phys.Rev.ST.Accel Beams 2, 081001 (1999)

Detailed studies have shown that Muon Colliders are probably feasible, but are very challenging and require a lot of hardware development. We could really do with a less ambitious step towards a Muon Collider that helps us climb the learning curve.

Muon Collider Motivation

$(m_\mu / m_e = 207)$

1. Less synchrotron radiation; Energy radiated per turn in a ring of radius ρ (km):

   $$W = 0.0078\ E^4 / \rho \quad \text{keV / turn}$$

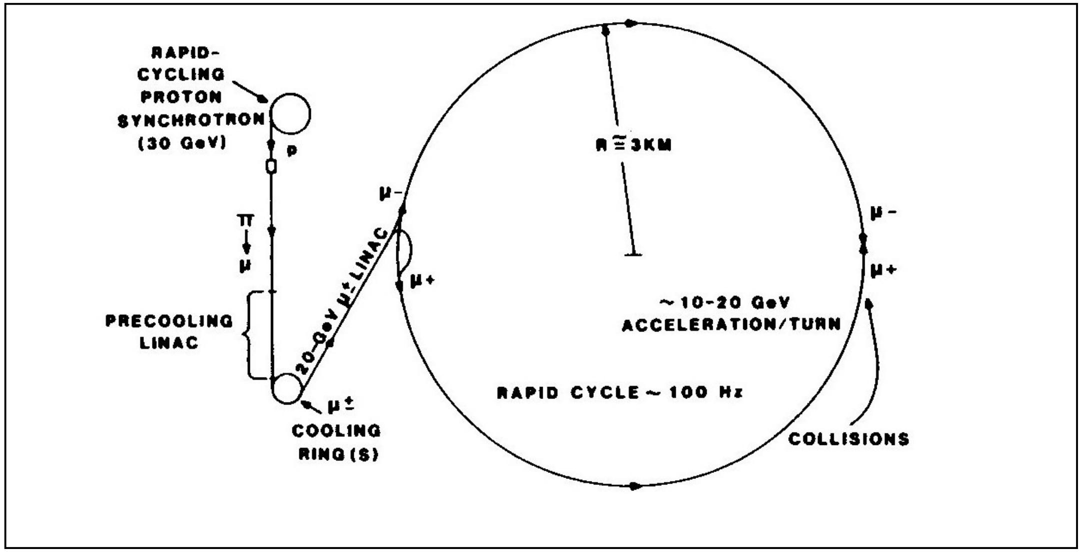
   → higher energy muons can be stored in a ring
   → multi-TeV Muon Collider plausible
   → compact fits on existing accelerator laboratory sites

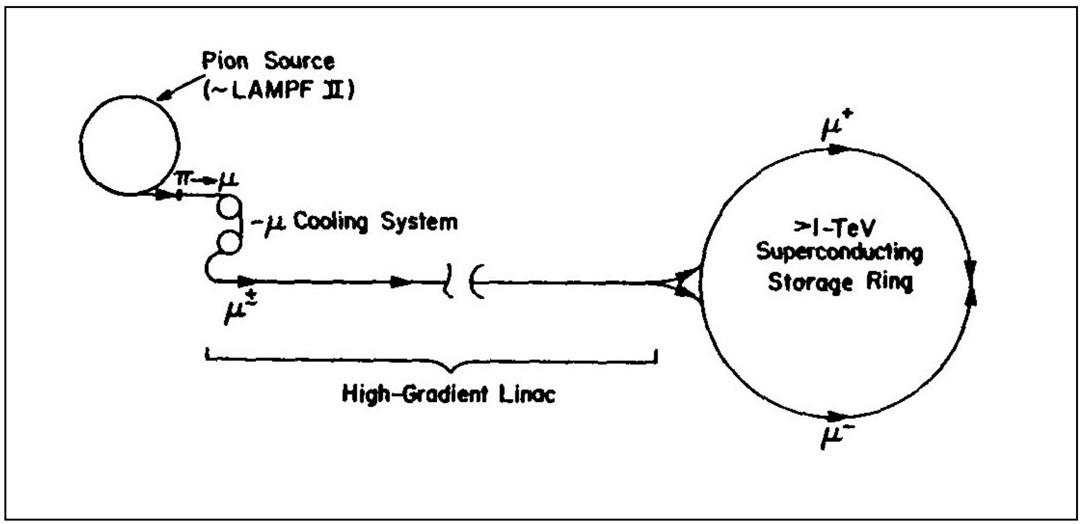
2. Negligible beamstrahlung → a Muon Collider can be operated with an energy spread of as little as 0.01% → precision measurements of masses and widths.

3. S-channel Higgs production. Since the coupling is proportional to mass, muon colliders have an advantage of $(207)^2 = 40{,}000$ over electron-positron colliders.

Early Muon Collider Ideas

Neuffer, Proc. 12th Int. Conf. High Energy Accelerators (1983) 481





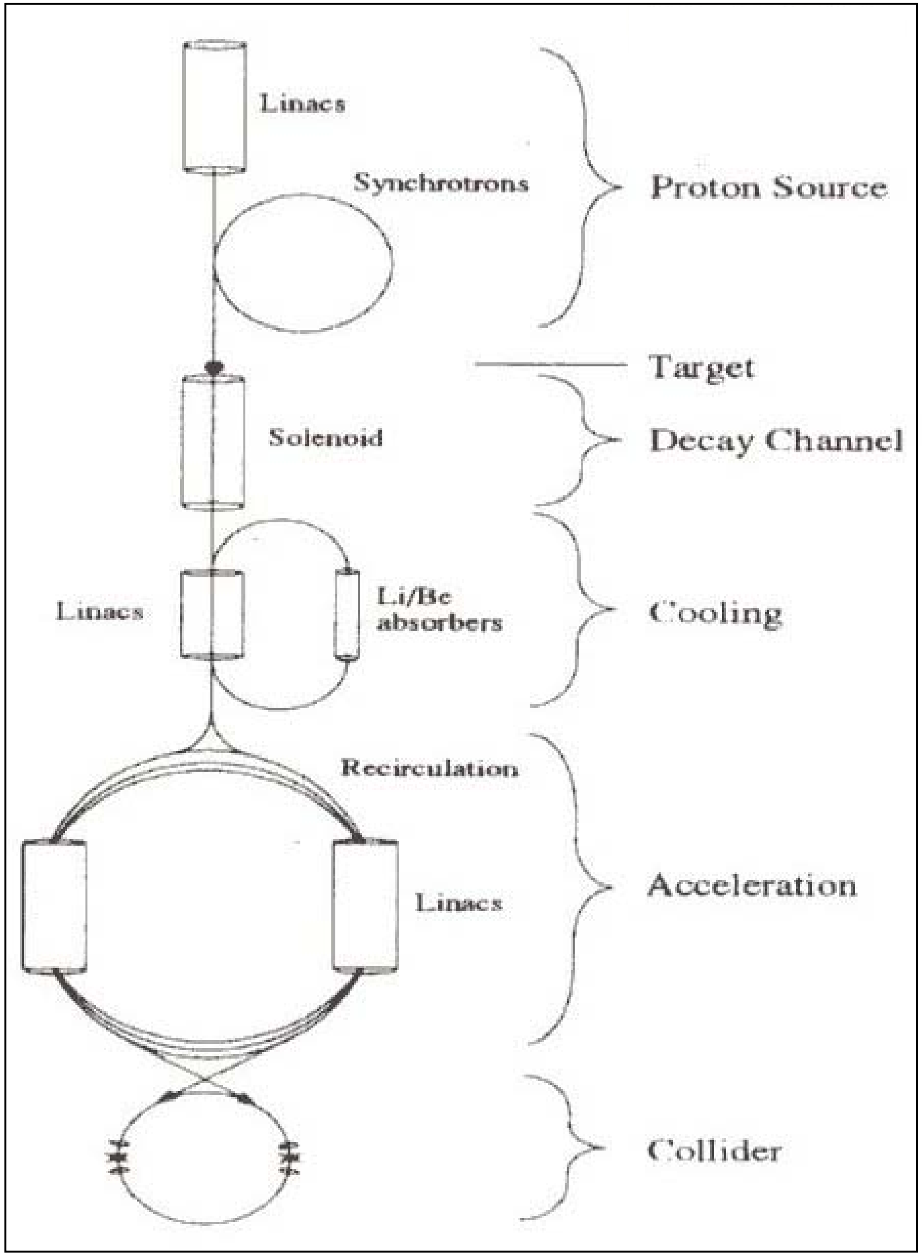
Early ideas for how to design a Muon Collider were important for motivating more detailed work. However, there was not much substance behind these ideas until ….

Birth of the Muon Collider Collaboration

1. The realization that, with modern technology, Muon Colliders might be feasible became apparent at the Sausalito Workshop in 1994. An informal collaboration was formed by BNL and FNAL to make a make a Muon Collider feasibility study for the Snowmass meeting in July 1996.

2. The Muon Collaboration was extended to include physicists and engineers from LBNL, ANL, KEK, DESY, and various Universities. The collaboration produced a 480 page study report for the Snowmass meeting (83 authors). No show-stoppers were identified – A multi-TeV Muon Collider appeared feasible although a hardware R&D program, and more detailed design work, were needed.

Muon Collider Concept in 1996



Muon Collider: A Feasibility Study (Snowmass 1996), BNL-52503, FNAL-Conf-96/092, LBNL-38946

		4 TeV	.5 TeV	Demo.
Beam energy	TeV	2	.25	.25
Beam γ		19,000	2,400	2,400
Repetition rate	Hz	15	15	2.5
Muons per bunch	10^{12}	2	4	4
Bunches of each sign		2	1	1
Normalized *rms* emittance ϵ^N	$10^{-6}\pi\,\mathrm{m}-\mathrm{rad}$	50	90	90
Bending Field	T	9	9	8
Circumference	km	7	1.2	1.5
Average ring mag. field B	T	6	5	4
Effective turns before decay		900	800	750
β^* at intersection	mm	3	8	8
rms beam size at I.P.	μm	2.8	17	17
Luminosity	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	10^{35}	5×10^{33}	6×10^{32}

Muon Collider Collaboration: May 1997

In May 1997, at its Orcas Island Meeting, the Muon Collaboration became a formal entity, with ~100 physicists and engineers participating. The collaboration subsequently requested funding support from the US DOE.

Spokesperson:	Bob Palmer (BNL)
Associate Spokespeople:	Andy Sessler (LBNL) Alvin Tollestrup (FNAL)

The collaboration embarked on three areas of intensive activity:

1. Theory and design simulations
2. Targetry R&D
3. Cooling channel R&D

Muon Collaboration Oversight and Review

To get significant funding for the R&D program required an organization which provided oversight and technical reviews :

MCOG		
T. Kirk	(BNL)	
S. Holmes	(FNAL)	First Chair
P. Oddone	(LBNL)	

Muon Collaboration Oversight Group comprising of a representative from the Directorates of each of the participating laboratories.

MUTAC

Technical review committee

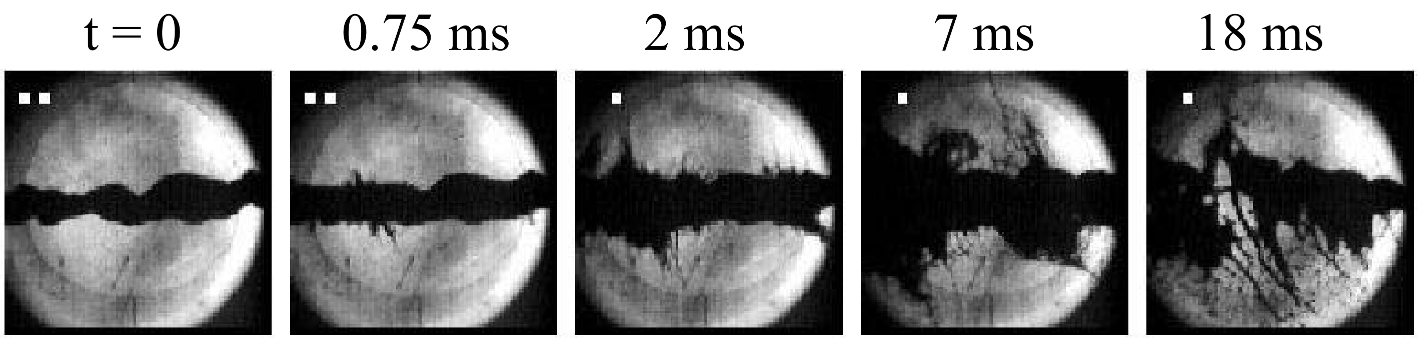
Muon Technical Advisory Committee reports to MCOG who transmits annual technical review reports to the funding agencies.

MCOG & MUTAC were created in 1998-9. The Collaboration received its first significant funding in Spring 1998.

Hardware R&D Collaborations - Targetry

http://www.hep.princeton.edu/mumu/target/

Spokesperson: K. McDonald



1. Simple tests of liquid metal targets
2. Liquid jet tests entering 20T solenoid
3. Liquid jet tests in intense proton beam
4. Add 20T pulsed magnet to the beam tests
5. Add 70 MHz cavity downstream of target
6. Surround cavity with 1.25T magnet
7. Characterize pion yield from target/magnet system
8. Simulation of thermal hyraulics of liquid-metal target system

Target R&D Program as initially envisioned

Hardware R&D Collaborations - MUCOOL

http://www.fnal.gov/projects/muon_collider/cool/cool.html

Spokesperson: S. Geer

MUCOOL MISSION

Design, prototype, & bench-test all cooling channel components & eventually beam-test a cooling section

1. Develop special RF modules giving high peak accelerating gradients at (30 MV/m at 805 MHz)
2. Design, build, and test an *Alternating Solenoid Transverse Cooling* section
3. Design, build, and test a Wedge energy cooling stage
4. Develop long liquid lithium lenses with a high surface field
5. Build short cooling sections and test their performance in a low energy muon beam

Cooling R&D Program as initially envisioned

Change of Focus: Muon Colliders to Neutrino Factories

In the summer of 1999 the Muon Collider Collaboration became the Neutrino Factory & Muon Collider Collaboration (often abbreviated to Muon Collaboration or MC), and the emphasis of the R&D changed from Muon Colliders to Neutrino Factories.

This happened because:

i) The MC, which had been studying low energy muon colliders, high energy muon colliders, and neutrino factories (proposed in Nov. 1997) had just had their first MUTAC review, and were told to focus on an in-depth end-to-end study of one thing. The MC had to chose !

ii) Muon Colliders were by then known to be technically challenging. A less demanding "learning project" was perceived to be desirable to drive the development of intense muon sources; a Neutrino Factory for example.

iii) Driven by the SuperK atmospheric neutrino results, and the prospects of measuring CP violation in the neutrino sector, the neutrino community had lots of enthusiasm for Neutrino Factories.

Bibliography: Neutrino Factory Papers (with the most citations)

The work on Muon Collider design by the US Muon Collider collaboration established the probable feasibility of a millimole per year muon source. The idea of using a Muon Collider type muon source together with a storage ring with long straight sections to produce an intense neutrino source was proposed in November 1997 :

Geer, Workshop on Physics at the First Muon Collider & Front End of a Muon Collider, Nov. 1997; FERMILAB-PUB-97-389; PRD 57, 6989 (1998)

De Rujula, Gavela, Hernandez; hep-ph/9811390, Nucl. Phys.B547:21-38,1999.
Barger, Geer, Raja & Whisnant, hep-ph/9911524, Phys. Rev. D62:013004, 2000
Barger, Geer, Raja & Whisnant, hep-ph/0003184, Phys. Rev. D62:073002, 2000
Cervera, Donini, Gavela, Gomez Cadenas, Hernandez, Mena & Rigolin, hep-ph/0002108, Nucl. Phys. B579:17-55, 2000.
Freund, Linder, Petcov, Romanino, hep-ph/9912457, Nucl. Phys. B578:27-57, 2000

This early work established Neutrino Factories as the tool of choice for probing very small values of θ_{13}, precision parameter measurements, determining the neutrino mass hierarchy, and searching for CP violation in the lepton sector.

The Neutrino Factory Concept

S. Geer, FERMILAB-PUB-97-389; PRD 57, 6989 (1998)

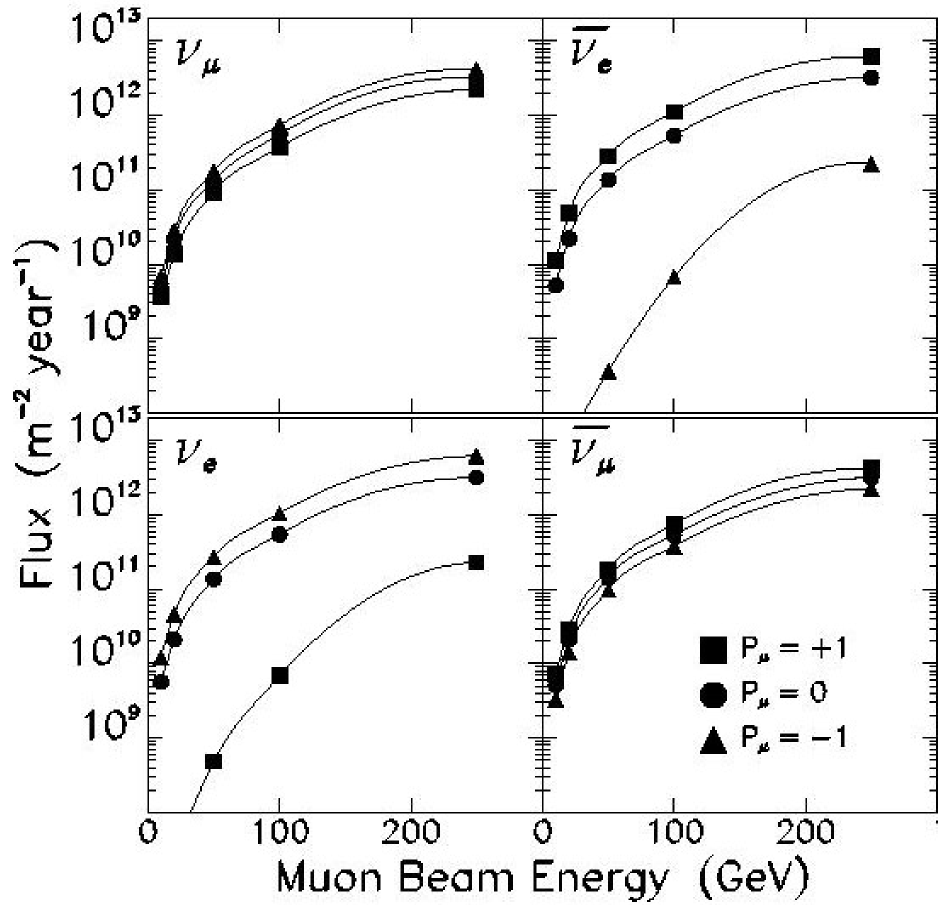
1. Proposed using a Muon-Collider-type Muon source, together with a muon storage ring with long straight sections, to produce a very intense neutrino source (later called a Neutrino Factory)

2. Calculated fluxes → thousands of events in a reasonably sized detector on the other side of the Earth !)

3. Proposed using wrong-sign muons to search for $\nu_e \rightarrow \nu_\mu$ oscillations → impressive sensitivity

4. Proposed exploiting polarization to control the neutrino energy spectra

Fluxes on the other side of the Earth (L = 10,000 km)

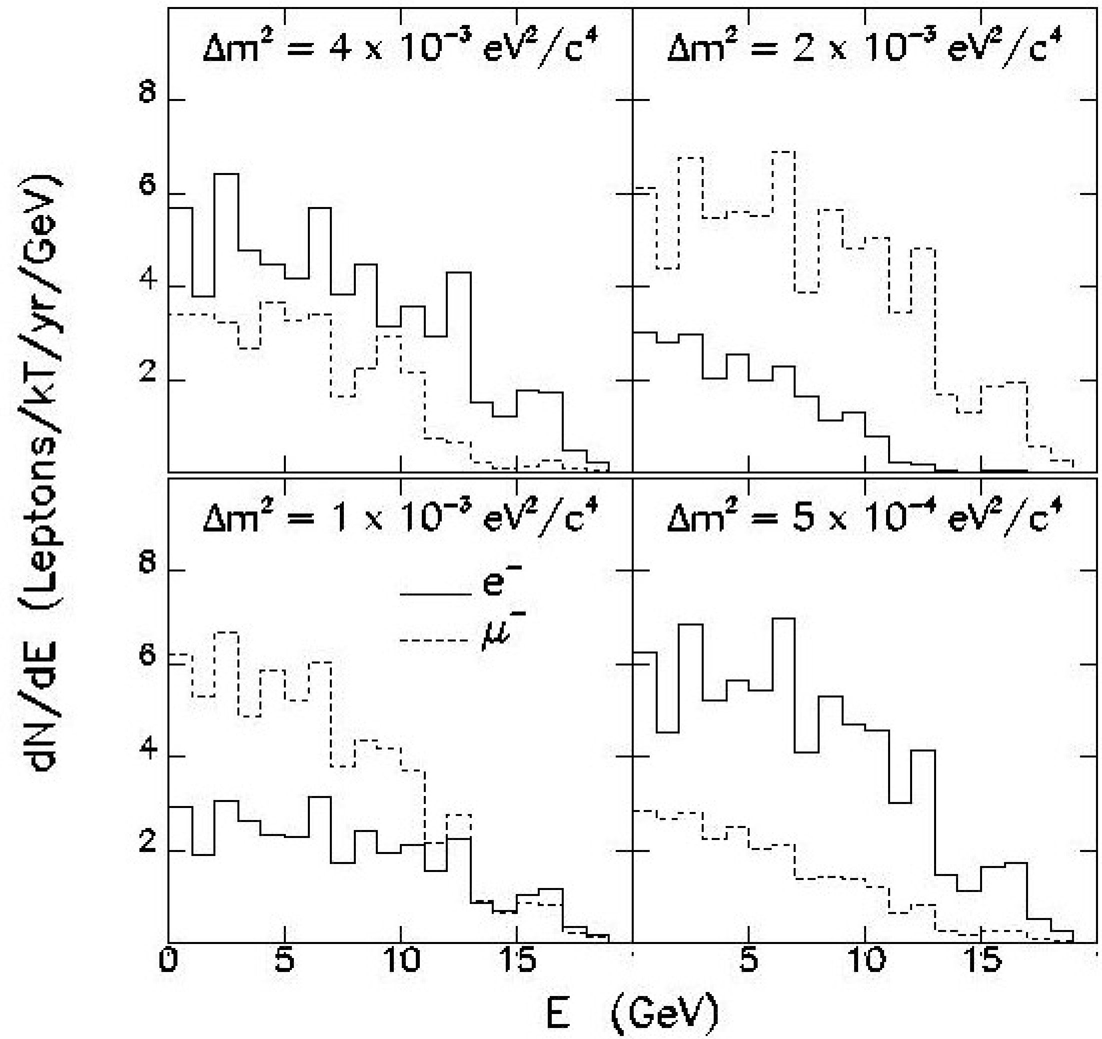


The Neutrino Factory Concept - 2

Measurements of the lepton spectra from CC interactions can be used to determine the oscillation parameters.

Sensitive to $\nu_e \rightarrow \nu_\mu$ oscillations down to oscillation amplitudes of 10^{-4} or lower !

Lepton Rates from 20 GeV Storage Ring, L = 10,000 km
S. Geer, PRD 57, 6989 (1998)

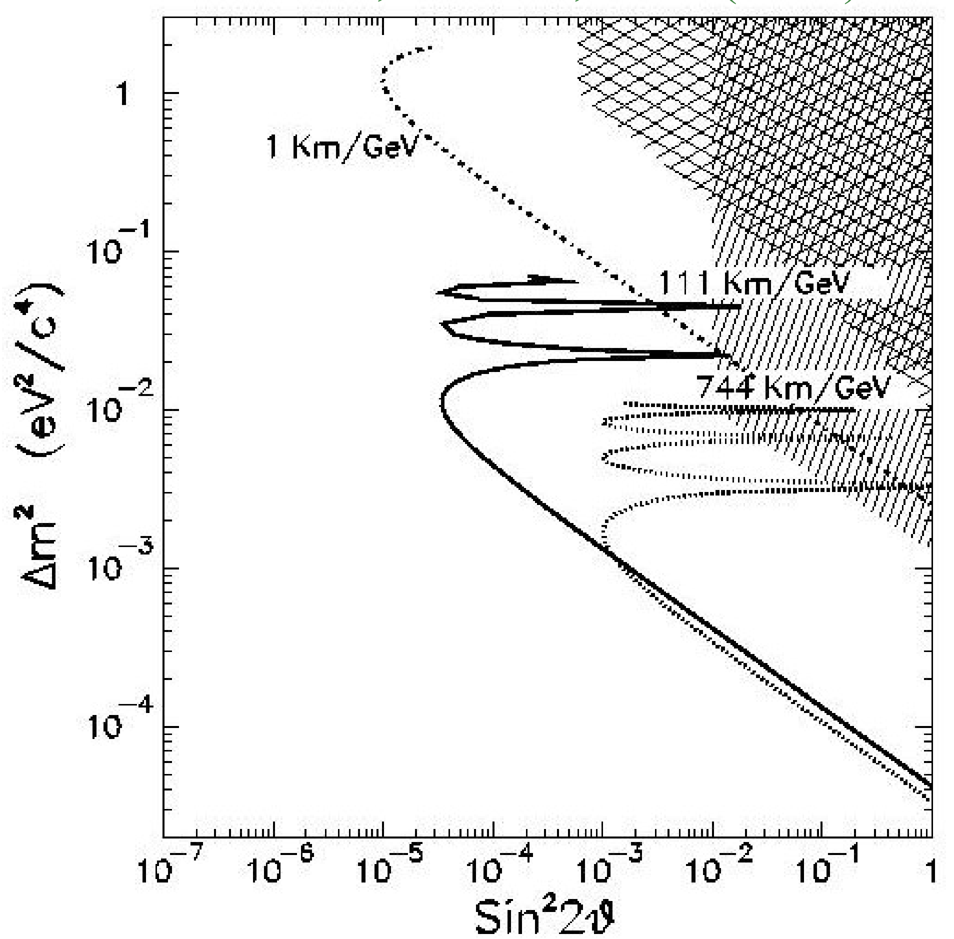


The Neutrino Factory Concept - 3

Analysis was based on a 20 – 50 GeV Neutrino Factory providing 2×10^{20} useful muon decays per year, and a detector with a 10 kt fiducial mass.

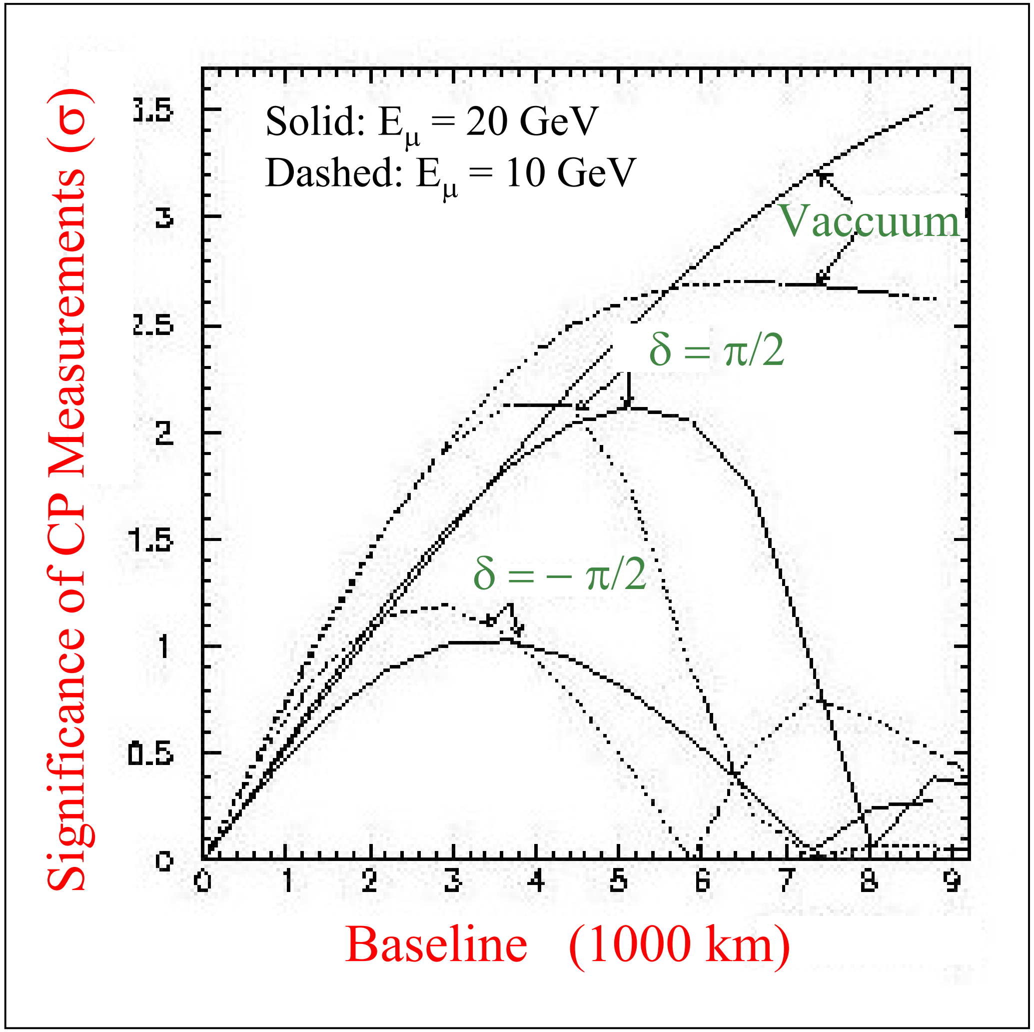
Detector masses of 50 kt or more are now considered reasonable for long-term neutrino physics, and since backgrounds to wrong-sign muon events can be kept at the 10^{-4} level or lower, the sensitivity of a neutrino factory may be even better than originally anticipated.

S. Geer, PRD 57, 6989 (1998)



Consolidating the Physics Case: CP Violation

De Rujula, Gavela, Hernandez; hep-ph/9811390, Nucl. Phys.B547:21-38,1999

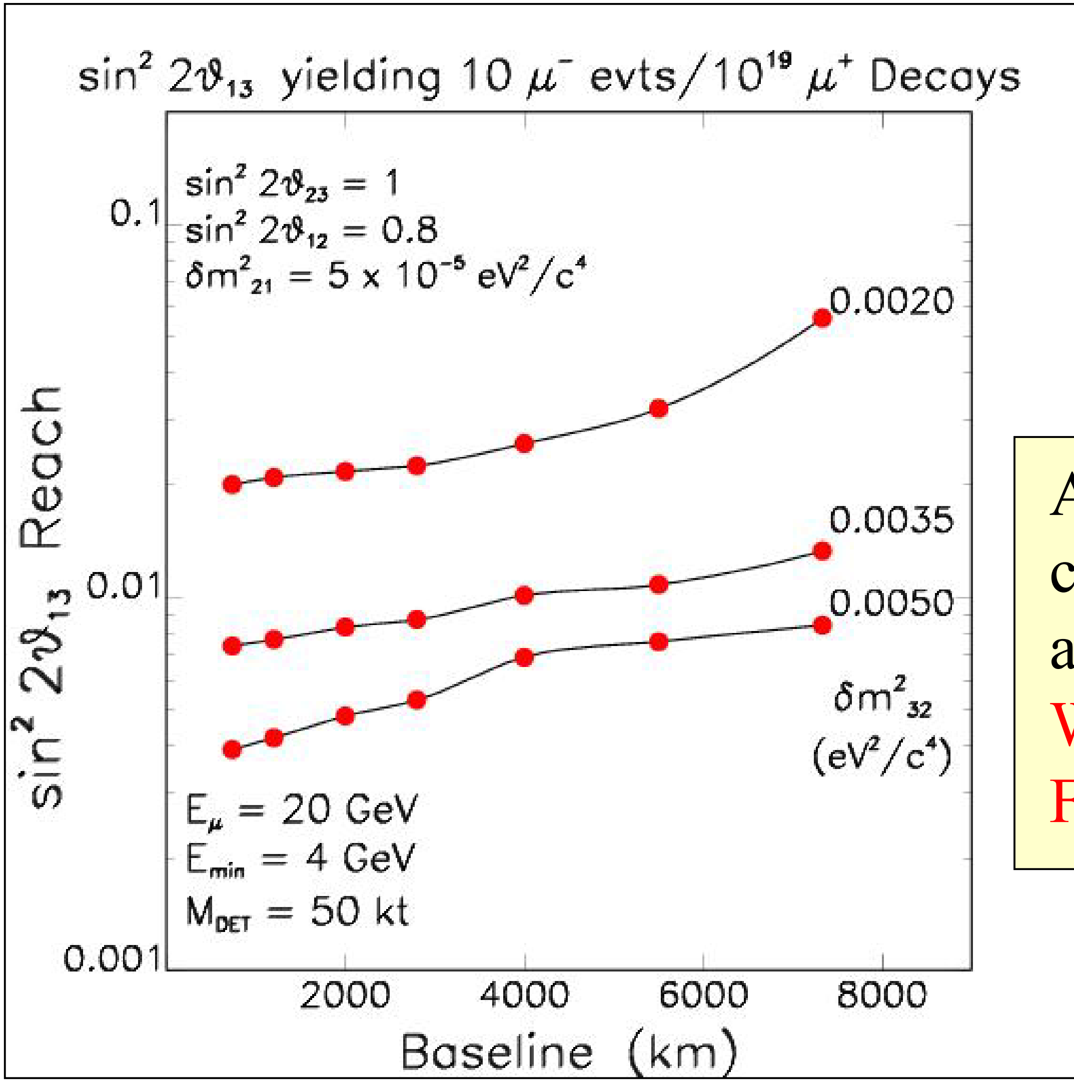


In 1998 (published in 1999) De Rujula et al showed that Neutrino Factory measurements might be able to measure CP violation in the lepton-sector provided the solar neutrino solution was the MSW Large Mixing Angle solution.

This result fueled the interest in Neutrino Factories.

Consolidating the Physics Case: θ_{13}

Barger, Geer, Raja, Whisnant, PRD 62, 073002

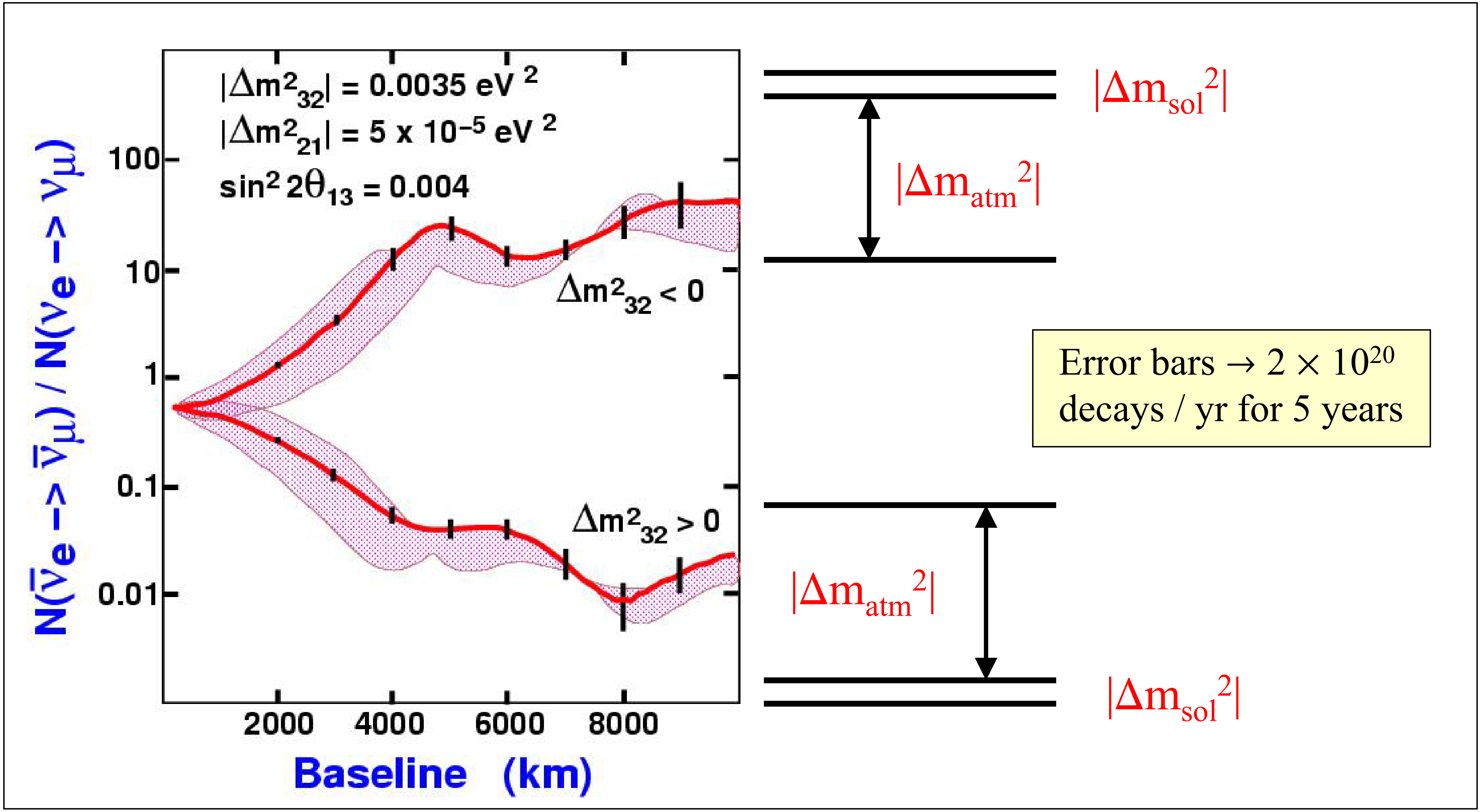


Many groups studied the sensitivity to small values of θ_{13} :

At a Nu Factory 10^{19} decays yield comparable reach to 5 yrs running at the 0.77 MW JHF Superbeam.
With 2×10^{20} decays/yr, a Nu-Factory does $\times$ 100 better.

Consolidating the Physics Case: Matter Effects

Barger, Geer, Raja, Whisnant, PRD 62, 073002; S. Geer, hep-ph/0008155



Bibliography: Neutrino Factory Design and Physics Studies

The emerging evidence for neutrino oscillations from the Super-K Experiment, together with the widespread interest in the Neutrino Factory concept, led to a series of detailed Neutrino Factory design studies, which established technical feasibility and defined the R&D that needs to be done enable these new neutrino sources to become a reality.

US Design Study 1 (Eds. Finley, Holtkamp) ;
http://www.fnal.gov/projects/muon_collider/nu-factory/

US Design Study 2 (Eds. Osaki, Palmer, Zisman, Gallardo) ;
http://www.cap.bnl.gov/mumu/studyii/FS2-report.html

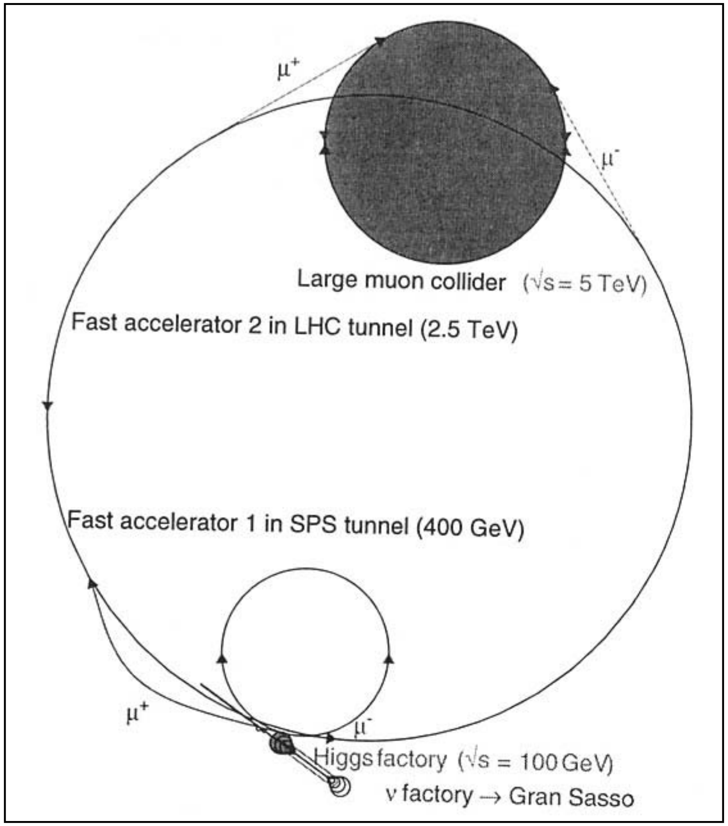
Physics Study: (Eds. Geer, Schellman) hep-ex/0008064
Front-End Physics Study: M. Mangano et al, hep-ph/0105155
Muon Collider ν physics: Bigi et al, hep-ph/0106177 (B. King initial work)

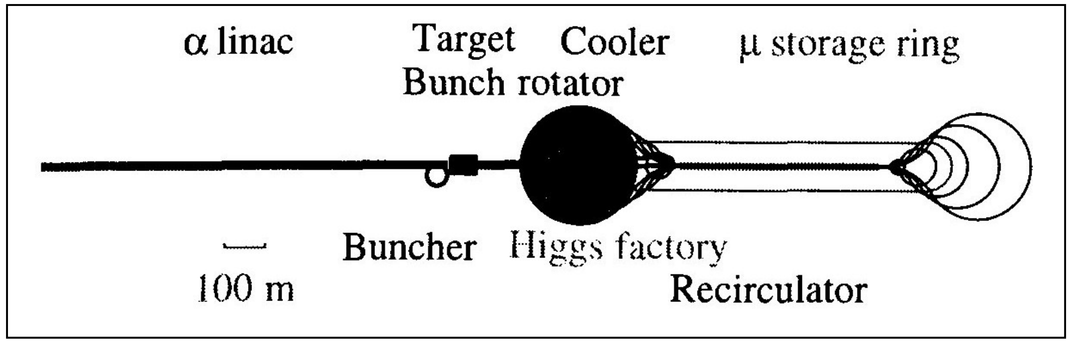
CERN Study (Eds. Autin, Blondel, Ellis) April 1999, CERN 99-02
Japanese Study (Eds. Kuno , Mori) May 2001
Status Report (Ed. Raja) Aug. 2001, hep-ex/0108041

CERN Initial Study

B. Autin, A. Blondel, J. Ellis (Editors), "Prospective Study of Muon Storage Rings at CERN", CERN 99-02, ECFA 99-197 (April 1999).

"This report presents the conclusions of a six-month prospective study, encouraged by ECFA, on the physics opportunities and accelerator issues presented by muon colliders, and by extension, muon storage rings."





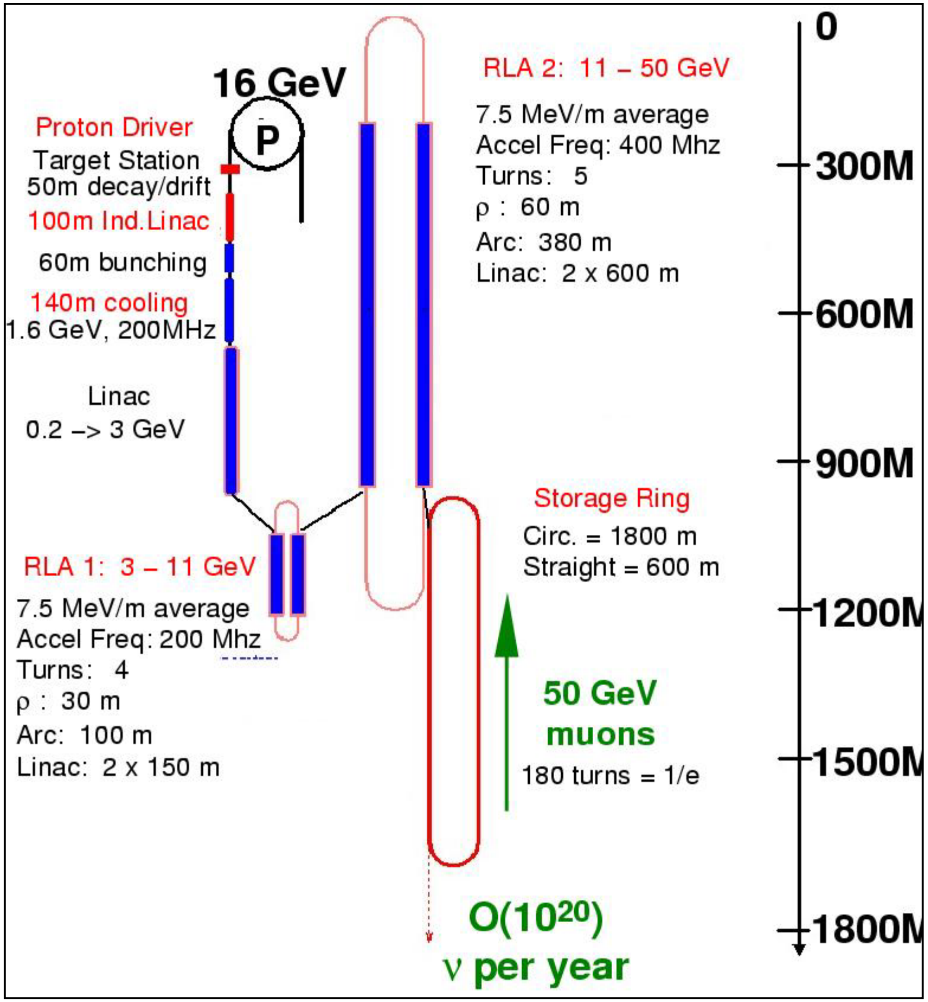
Reviewed US design ideas, putting them in the context of a possible future CERN facility.

Considered three steps: Neutrino Factory → Higgs Factory → High Energy Muon Collider

US Design Study 1 (completed April 2000)

N. Holtkamp, D. Finley (editors); 279 authors.

Six-month study with full participation of the Muon Collaboration, and important contributions from Labs around the world → Lots of engineering.



Proton driver: Upgraded FNAL Booster

Carbon target in 20T capture solenoid

50m decay channel (1.25T)

Muon energy spread reduced using induction linac (phase rotation)

Muons bunched at 200 MHz

Transverse phase space reduced using an ionization cooling channel

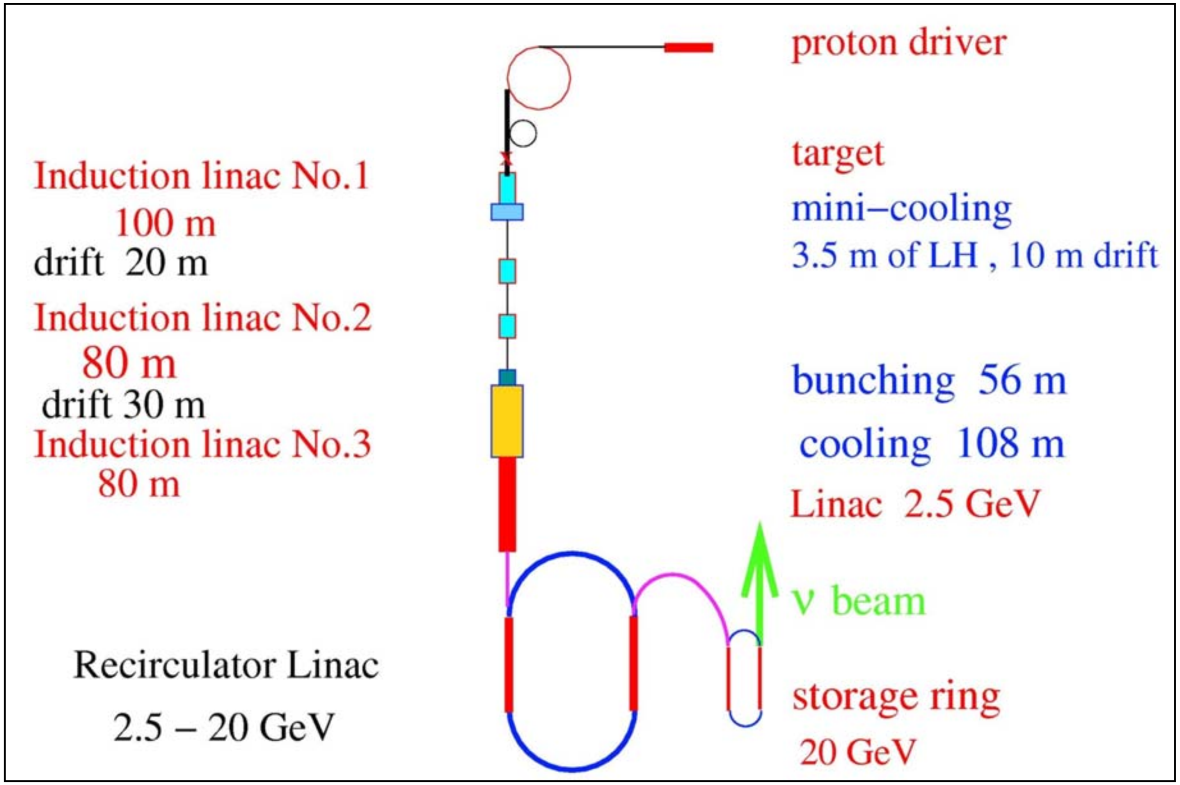
Acceleration to 50 GeV in RLAs

US Design Study 1 Result

"The result of this study clearly indicates that a neutrino source based on the concepts presented here is technically feasible. According to our current understanding it will not quite meet the intensity specified and it should probably have an energy lower than originally specified (50 GeV). There is clear indication though that we would and should improve the performance, and also how it could be done … ."

US Design Study 2 (completed May 2001)

Osaki, Palmer, Zisman, Gallardo (editors); 200 authors.



Based on upgraded BNL AGS

Hg jet target, better induction linac & cooling channel designs

Achieved 6 x Study 1 muon rate
>> 2×10^{20} useful μ decays / year

Present US Organization

Muon Collaboration (~150 members)

A. Sessler	(LBNL)	Spokesperson
R. Palmer	(BNL)	Assoc. Spokesperson
A. Tollestrup	(FNAL)	Assoc. Spokesperson
M. Zisman	(LBNL)	(Project Manager)

MCOG

T. Kirk	(BNL)	Chair
S. Holmes	(FNAL)	
P. Oddone	(LBNL)	

MUTAC

H. Edwards	(FNAL)	Chair
M. Breidenbach	(SLAC)	
G. Dugan	(Cornell)	
M. Harrison	(BNL)	
J. Hastings	(BNL)	
Y.-K. Kim	(LBNL)	
C. Leemann	(Jefferson)	
J. Lykken	(FNAL)	
A. McInturff	(LBNL)	
U. Ratzinger	(GSI)	
R. Ruth	(SLAC)	
K. Yokoya	(KEK)	

Neutrino Factory & Muon Collider Collaboration : Present Organization

http://www.cap.bnl.gov/mumu/mu_home_page.html

Executive Board

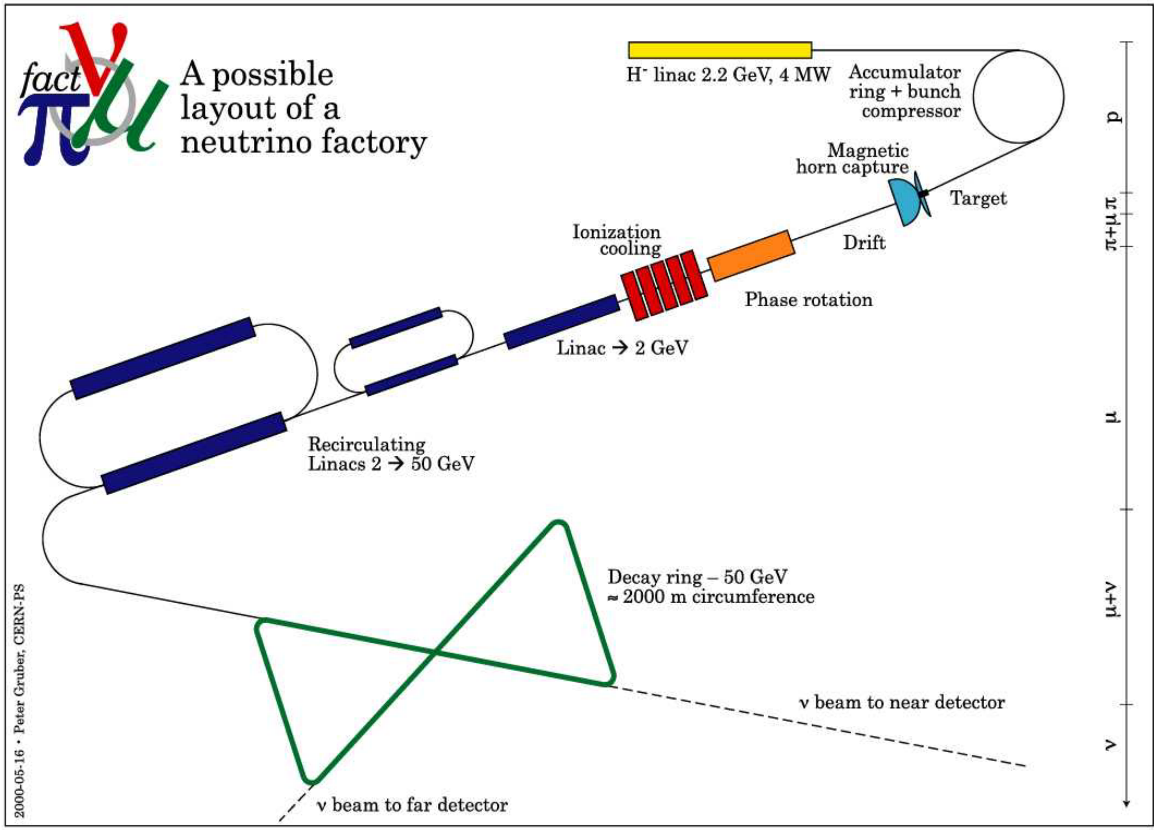
A. Sessler	(LBNL)	Spokesperson
R. Palmer	(BNL)	Assoc. Spokesperson
A. Tollestrup	(FNAL)	Assoc. Spokesperson
J. Gallardo	(BNL)	
D. Cline	(UCLA)	
D. Errede	(U. Illinois)	
S. Geer	(FNAL)	(MUCOOL Spokesperson)
D. Kaplan	(IIT)	(MICE US Spokesperson)
K. McDonald	(Princeton)	(Targetry Spokesperson)
A.Skrkinsky	(BINP)	
D. Summers	(U. Mississippi)	
M. Tigner	(Cornell Univ.)	
J. Wurtele	(LBNL/Berkeley)	
M. Zisman	(LBNL)	(Project Manager)

Technical Board

S. Geer	(FNAL)
D. Hartill	(Cornell)
H. Haseroth	(CERN)
H. Kirk	(BNL)
D. Kaplan	(IIT)
K. McDonald	(Princeton)
Y. Mori	(KEK)
R. Palmer	(BNL)
R. Raja	(FNAL)
R. Rimmer	(LBNL)
T. Roser	(BNL)
A. Sessler	(LBNL)
D. Neuffer	(FNAL)
M. Zisman	(LBNL)

CERN Studies

http://muonstoragerings.web.cern.ch/muonstoragerings/



Similar to US scheme but alternative technologies:

Lower energy proton driver (2.2 GeV protons)

Pion capture with magnetic horn

RF for phase rotation (no induction linac)

Transverse cooling channel With 44/88 MHz (not 200 MHz) RF cavities.

European Organization

EMCOG created April 2002. Its task is to “report to the funding agencies & laboratory directors, and be the point of contact with ECFA, and with other similar organizations in the US, and eventually in Japan.”

European MCOG (EMCOG)

Carlo Wyss (CERN director of accelerators, chair)
A. Mosnier, F. Pierre (CEA-DAPNIA)
O. Boine-Frankenheim, I. Hofmann (GSI)
M. Napolitano (Napoli)
A. Pisent (Legnaro)
S. Katsanevas, M. Lieuvin (IN2P3)
R. Eichler (PSI)
K. Peach (RAL)
A. Blondel (Switzerland and ECFA Contact)

European MCOG Goal

In their first meeting EMCOG declared that their initial goal was:

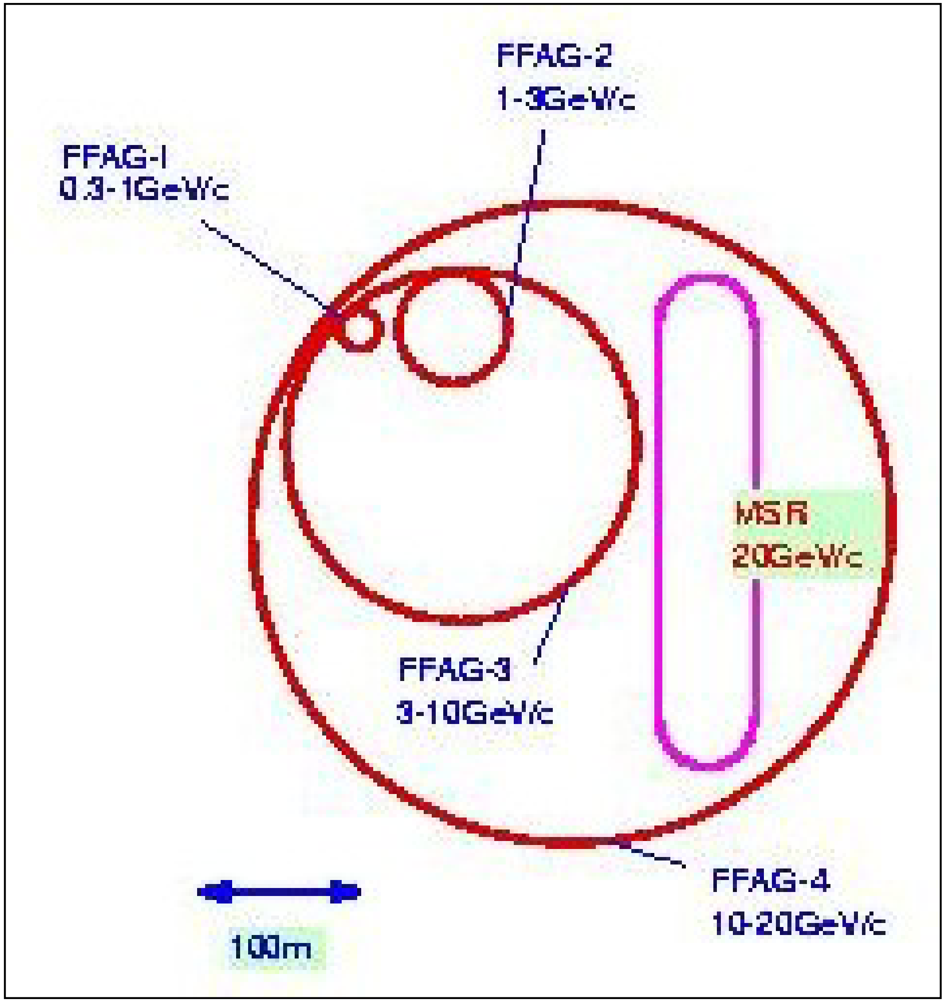
"… to have a Conceptual Design Report for a European Neutrino Factory Complex by the time of LHC start-up, so that, by that date, this would be a valid option for the future of CERN."

"… The emphasis should be the definition of practical experimental projects with a duration of 2-5 years. Such projects can be seen in The following four areas:

1. High intensity proton driver.
2. Target studies.
3. Horn studies.
4. MICE (Muon Ionization Cooling Experiment)"

A Feasibility Study of a Neutrino Factory in Japan - 1

http://www-prism.kek.jp/nufactj/index.html

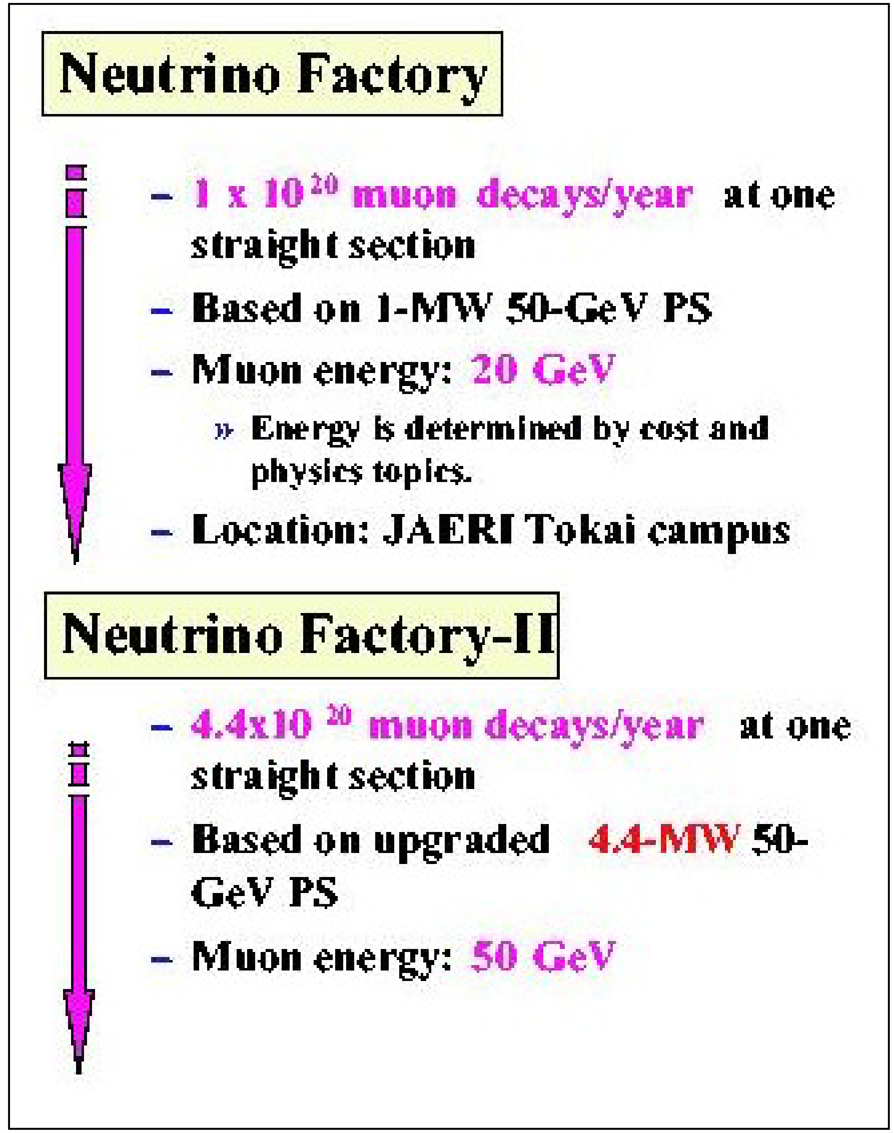


NuFACTJ Working Group, May 2001
(Editors: Y. Kuno, Y. Mori)
7 Authors

Scheme based on very large acceptance accelerators – no muon cooling needed (although some cooling would be beneficial)

A Feasibility Study of a Neutrino Factory in Japan - 2

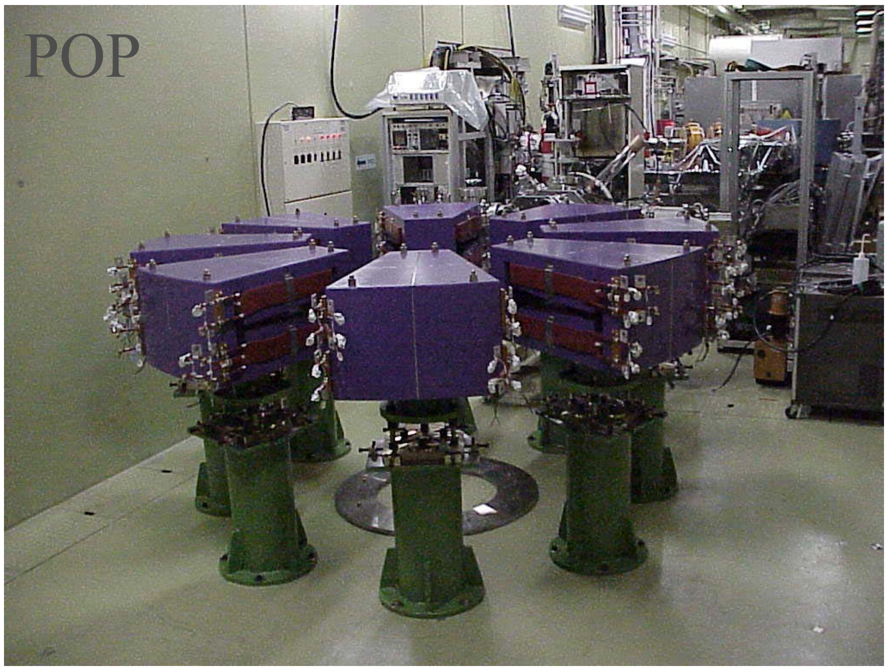
The Japanese Neutrino Factory Plan is based on an evolution of The new Japan Hadron Facility (JHF) which is currently under construction & is expected to begin operation in 2007
→ 0.8 MW 50 GeV proton synchrotron.

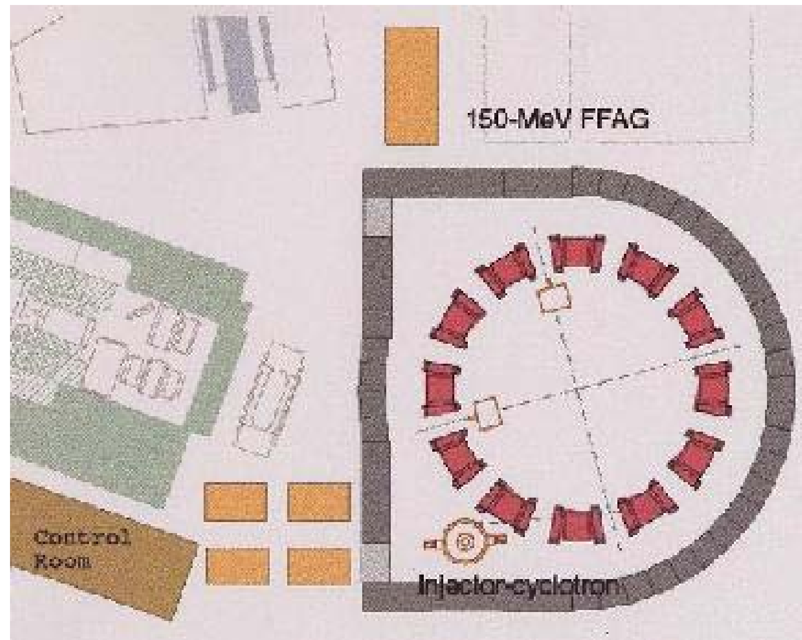


Japanese R&D

LARGE ACCEPTANCE ACCELERATORS - FFAGs

R&D Issues: RF, Injection/extraction, magnet design, dynamic aperture …





Proof of Principle (POP) FFAG
tested at KEK in June 2000

NEXT STEP : 150 MeV FFAG
under construction At KEK

Neutrino Factory R&D: An International Endeavor

Neutrino Factory R&D is becoming increasingly international in character:

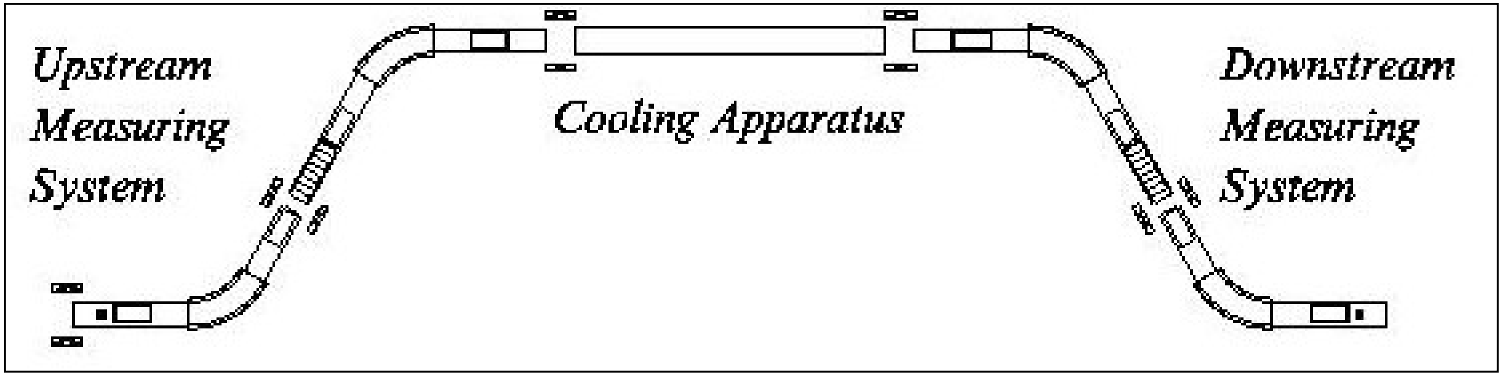
1. NUFACTXX Workshops
   - 1999 Lyon
   - 2000 Monterey, California
   - 2001 Tsukuba
   - 2002 London

2. CERN, Japanese, and UK participation in the US hardware R&D Collaborations (MUCOOL and Targetry)

3. International Cooling Experiment (MICE) being designed as a joint European-Japanese-US endeavor

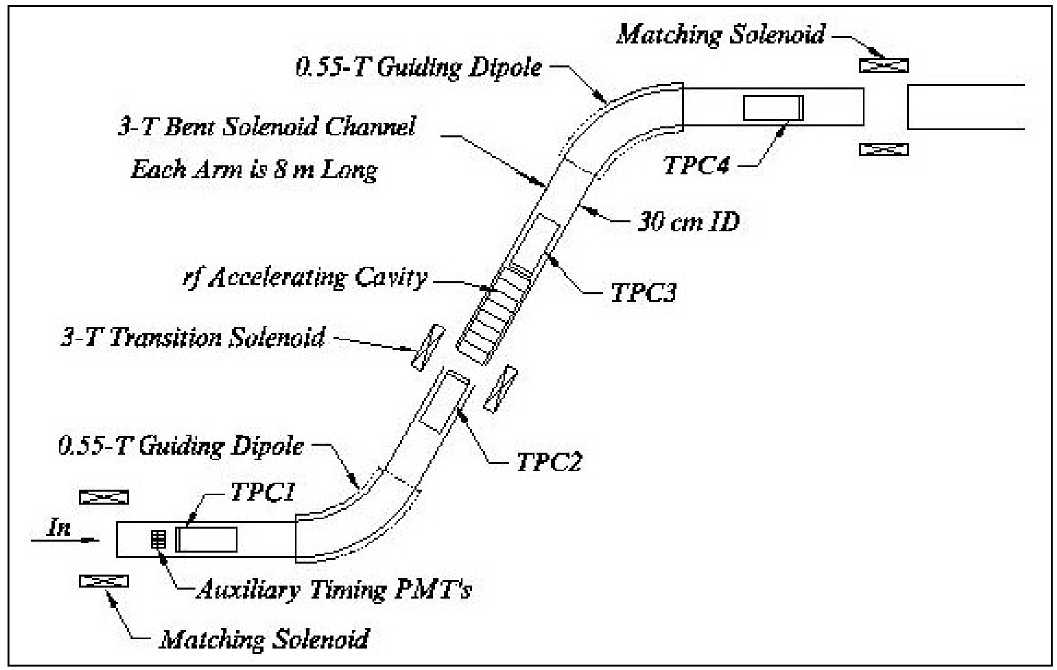
Resources are limited and, at the end of the day, we want to choose the best technologies

Example: The Cooling Experiment



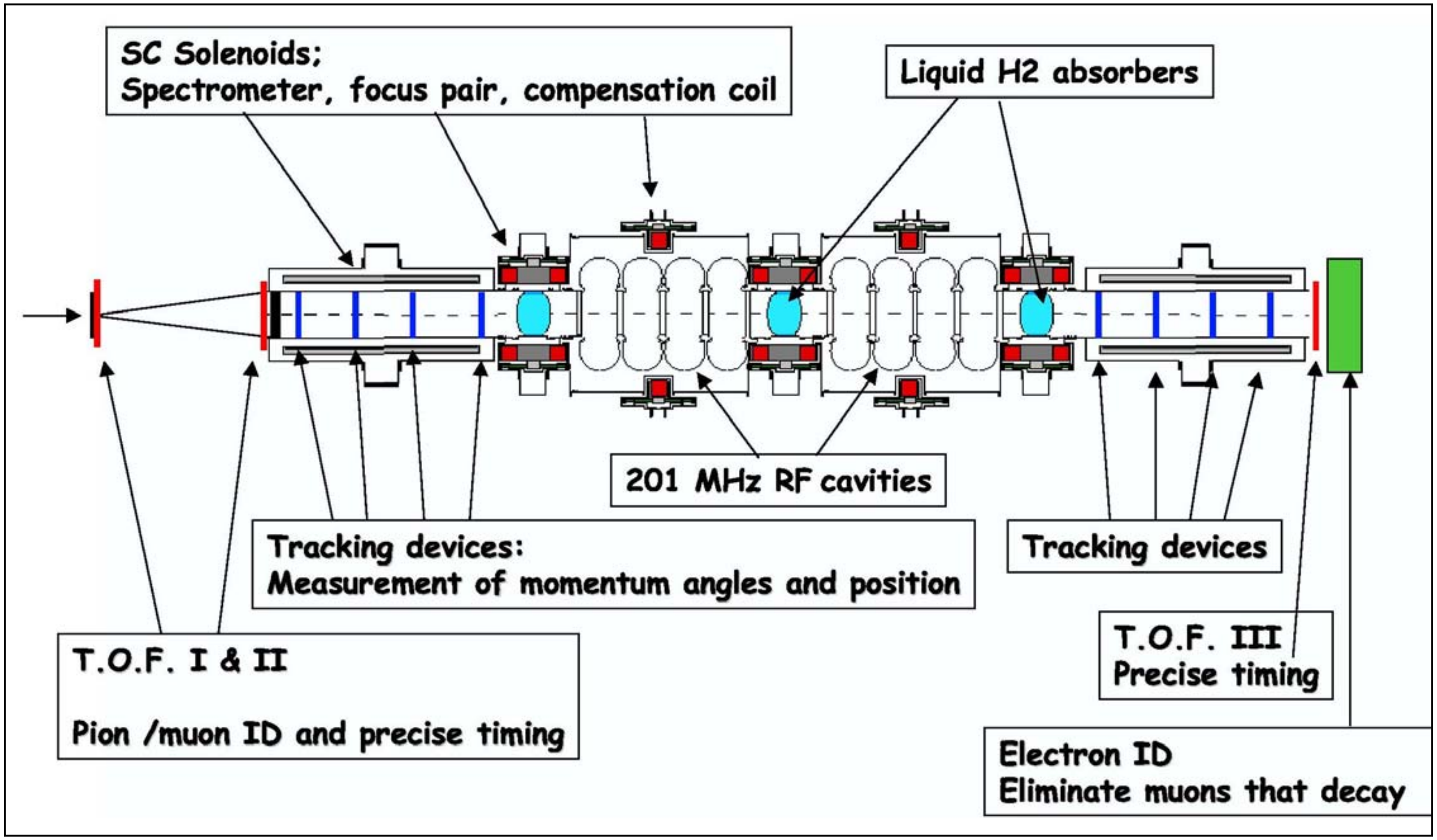
Originally proposed in the US as part of the MUCOOL R&D program: **P904 Proposal, April 1998**

Design proved **complicated and expensive** → concluded that an experiment of this scope needed to be international



MICE – An International Experiment

A simpler design than P904 (aided by the evolution of cooling channel designs based on lower frequency RF) was initially proposed at CERN & is being developed as an international cooling experiment → See Dan Kaplan's Talk



Proposal should be submitted within the next year

Final Remarks

We are in the midst of an exciting discovery: NEUTRINO OSCILLATIONS. Further neutrino oscillations experiments may reveal unexpected surprises.

Neutrino factories appear to be the tools of choice for future neutrino oscillation studies, offering precision and flexibility.

Neutrino factory design studies have come a long way. Neutrino Factories appear to be feasible.

We need a few years of hardware R&D to develop and test the required components.

We need to continue looking at new ideas that can reduce the cost of a Neutrino Factory.